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EFFECTS OF URBANIZED AREAS FOR NWP DMI-HIRLAM HIGH RESOLUTION MODEL OPERATIONAL RUNS

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Суточные изменения метеорологических величин (ветер на высоте 10 м и температура на высоте 2 м, поля потоков скрытого и явного тепла) в приземном слое как функция таких параметров, как шероховатость поверхности, альбедо и поток антропогенного тепла для урбанизированных территорий, оценены в соответствии со схемой ISBA (взаимодействие поверхность — биосфера — атмосфера). Эта схема модифицирована для урбанизированных ячеек моделируемой области. Метеорологическая модель DMI-HIRLAM (горизонтальное разрешение 1.4 км) запущена с модифицированными данными по типам подстилающей поверхности и климатологическими данными. Анализировалась отдельно взятая ситуация (30 марта 2005 года) с типичным доминирующим западным атмосферным переносом над островом Зиланд (Дания). Суточный ход метеорологических величин анализировался путем сравнения результатов (разностные поля величин для каждого срока) контрольного и модифицированного запусков модели. Оценено влияние урбанизированных территорий и пригородов Копенгагена (Дания) и Мальмо (Швеция).

Introduction

Modern nested Numerical Weather Prediction (NWP) and meso-meteorological models utilise land-use databases down to hundred metres of resolution or finer, and approach the necessary horizontal and vertical resolutions to provide weather forecasts for the urban scale [1]. In combination with recent scientific developments in the field of urban sub-layer atmospheric physics [2 – 5] and the enhanced availability of high-resolution urban surface characteristics, the capability of NWP models to provide high quality urban meteorological data will, therefore, increase.

Despite the increased resolution of existing operational NWP models, urban and non-urban areas mostly contain similar sub-surface, surface, and atmospheric boundary layer (ABL) formulations. These do not account for specific urban dynamics and energetics or for their impacts on the ABL simulation and its various characteristics (e. g. internal boundary layers, urban heat island, precipitation patterns). Additionally to weather forecast in urban areas, NWP model output is used for air pollution modelling and to be designed into suitable inputs

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for urban and meso-scale air quality models. Therefore, a revision of the traditional approach to urban air pollution forecasting is required. The current EU-project FUMAPEX: "Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure" [6], initiated by the COST-715, is focusing on this issue (web-site: `http://fumapex.dmi.dk`). The main objectives are to (i) improve meteorological forecasts for urban areas, (ii) connect NWP models to urban air pollution and population exposure models, (iii) build improved the Urban Air Quality Information and Forecasting Systems, and (iv) demonstrate their application in cities located in various European climates.

Improvements of urban scale meteorological forecasts will also provide information for city management regarding additional hazardous or stressing urban weather and climate. Moreover, the availability of such reliable forecasts could be of relevant support for the emergency management of fires, accidental toxic emissions, potential terrorist actions, etc.

Several variants of NWP urbanization are considered in the FUMAPEX project [7, 8], including modifications of the effective roughness and urban heat fluxes approach, the BEP urban sub-layer module [3] and the SM2-U urban soil model [4, 5]. They are different in requested computational time and not always suitable for operational NWP models [8].

Therefore, in this paper the focus is on the most inexpensive way of urbanisation. The diurnal variations of wind and temperature, fluxes fields in the low surface layer are analyzed on example of the DMI HIgh Resolution Limited Area Model (HIRLAM) model run taking into account modifications done in the Interaction Soil-Biosphere-Atmosphere (ISBA) scheme with respect to roughness, albedo, and anthropogenic heat flux (AHF) over the urban areas and surroundings of Copenhagen (CPH), Denmark and Malmö (MAL), Sweden.

1. Methods

1.1. DMI forecasts employing HIRLAM model

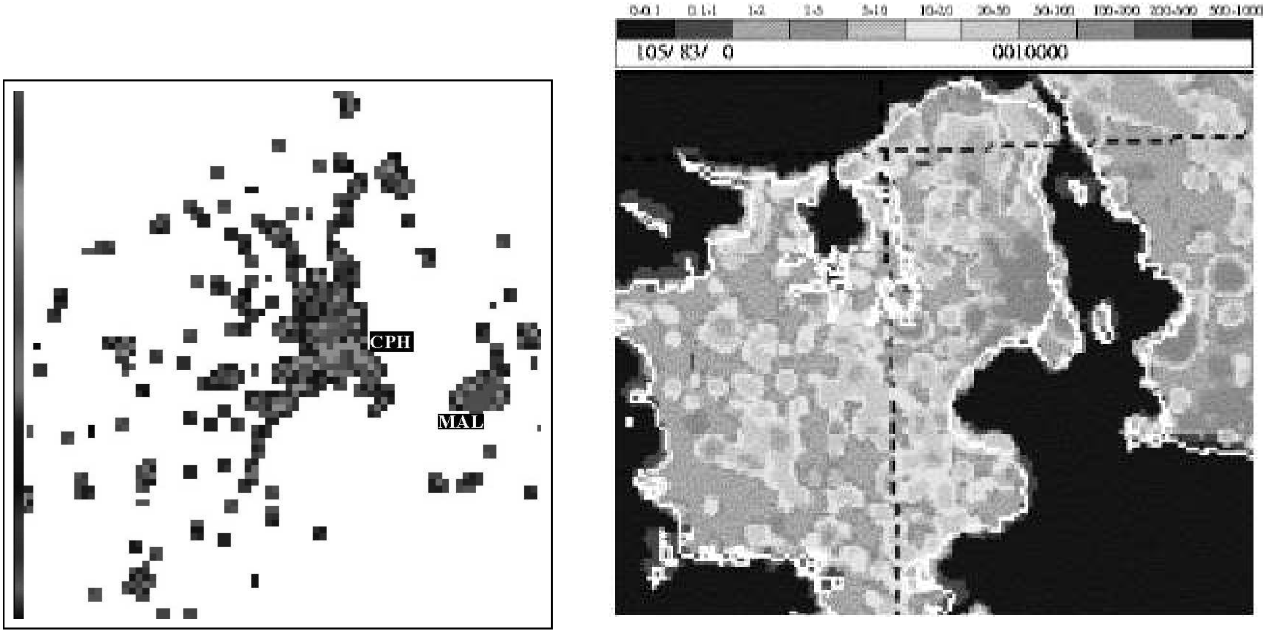
The DMI performs daily forecasts of meteorological fields employing the HIRLAM model [9]. The present DMI weather forecasting system [10] is based on HIRLAM 6.3. It consists of two nested models called DMI-HIRLAM-T15 and -S05. The models are identical, except for horizontal resolution (15 vs. 5 km) and geographical boundaries of domains. Both versions have 40 layers in the vertical. The lateral boundary values for T15, modelled every 6 hours, are from the ECMWF model. The system is run on NEC-SX6 supercomputer and produced model output files are archived on the mass storage system. The operational DMI-HIRLAM model applies an implicit digital filter initialization technique in order to remove the large amplitude gravity wave oscillations in the first few hours of forecast. The current operational DMI-model is semi-implicit, with semi-Lagrangian advection and leapfrog time stepping (with the semi-Lagrangian advection as optional). Physics such as short and long wave radiation, turbulence (except gravity wave drag), deep and shallow convection, cloud and precipitation generation and air-sea/air-land interactions are parameterized and included.

Additionally to the operational versions there are several experimental research DMI-HIRLAM models with the high-resolution of 1.4 km. These were run for limited periods for the Danish territory with a focus on the Copenhagen metropolitan area. The main assumptions in these models are identical to the operational versions, and boundary conditions are taken from T15 and S05. Modifications for the urban effects, considered in the following section, were included into high resolution runs.

1.2. Land use classification and parameters to distinct the urban features

The land use classification for the current version of DMI-HIRLAM is based on several datasets including CORINE, version 2000 [11]. Note, that in HIRLAM some fields, such as roughness, albedo, vegetation type, orography, etc. are assumed to be constant in modelling domains during operational runs. These fields are once produced and stored in the climate generation files (CGFs) and are available for analyses and forecasts. The reclassification of datasets into 20 major classes are performed following [12]. Then, it is reduced (based on the dominating and secondary class approach) into 5 major tiles of the ISBA land surface scheme [13 – 15]; in HIRLAM represented by water, ice, low vegetation, forest, and no vegetation. The characteristics (such as monthly leaf area index, albedo, roughness, etc.) of dominating types (from 20 classes) are used further in the ISBA calculation. In the scheme the urban class was treated with characteristics of bare soils modified with accordance of urbanized features. Therefore, the modification of these was used to test sensitivity of the DMI-HIRLAM model. The grid cells, where the urban class is presented, are shown in fig. 1, *a*. Although, the urban class type dominates only in less than 1 % of the cells of the domain, the greater attention was given for all cells, where urban class is, at least, presented.

To introduce the urban heat island effect into the ISBA scheme, an additional term, responsible for specifics of the urban heat fluxes, was added into the surface heat flux. This term includes the storage heat flux, parameterized by the OHM model [16, 17], and the anthropogenic heat flux, which depends on the density and type of the urban canopy [8]. It was considered proportionally to percentage of the urban class in a grid cell. Following estimations



a *b*

Fig. 1. Urban class presentation for the Copenhagen (CPH), Denmark and Malmö (MAL), Sweden metropolitan areas and surroundings (on left side of figure: scale in fractions of urban class representation in grid cell: top as 1, bottom as 0.01, white — no urban class presented in grid cell) (*a*); spatial distribution of roughness length in the urban part of the modelling domain (*b*).

of the average anthropogenic heat fluxes for cities in different climate zones [18], in this study the reference value (for complete urban surface) of the anthropogenic flux was varied up to 200 W/m^2.

Surface fluxes are calculated in HIRLAM for each grid cell using percentage of different land-use classes, mentioned above, in the grid cell, therefore, for the high-resolution runs (1.4 km) different parts of the urban areas are treated differently (e. g., the city center and suburb areas). One example of the spatial distribution of the roughness length (stored in CGFs) for the Copenhagen-Malmö urban areas of the modelling domain is shown in fig. 1, *b*.

2. Results and discussions

Several typical specific cases/dates during spring of 2005 were run employing the DMI-HIRLAM high resolution model. I.e. dates, when the dominating atmospheric transport over Zeeland from the south-east sector was observed with typical winds conditions, were studied. In these runs in the ISBA scheme, first, the roughness for cells, where the urban class was represented in the modeling domain, was increased up to 1 and 2 m. Second, the albedo was changed up to 0.80. Third, the contribution of anthropogenic heat flux ranging from 10 to 200 W/m^2 was incorporated into the scheme. In this paper, an example of such a case — DMI-HIRLAM run for 30 March 2005, 00 UTC + 24 hour forecast — is analyzed.

The meteorological fields' simulations for the urbanized areas were driven using boundary conditions of the DMI-HIRLAM-S05 model. These conditions were used as input for simulation of meteorological fields for the DMI-HIRLAM research version with resolution of 1.4 km, which includes the Copenhagen and Malmö metropolitan areas and surroundings. Note, for each date 8 independent runs were performed: 1 standard control run (no modifications in ISBA scheme); and modified: 4 — for anthropogenic heat fluxes, 2 — for roughness, and 1 — for albedo.

The diurnal cycle of meteorological variables such as wind velocity (at 10 m) and temperature (at 2 m) as well as sensible and latent heat fluxes were analyzed comparing outputs of the control run vs. runs with modified parameters for urban class. At each UTC term, the 2D (values in latitude vs. longitude gridded domain) difference fields for mentioned variables were produced/analyzed by subtracting outputs from the control run without any changes made vs. run with changes made for roughness, albedo, and anthropogenic heat flux.

Synoptic Situation

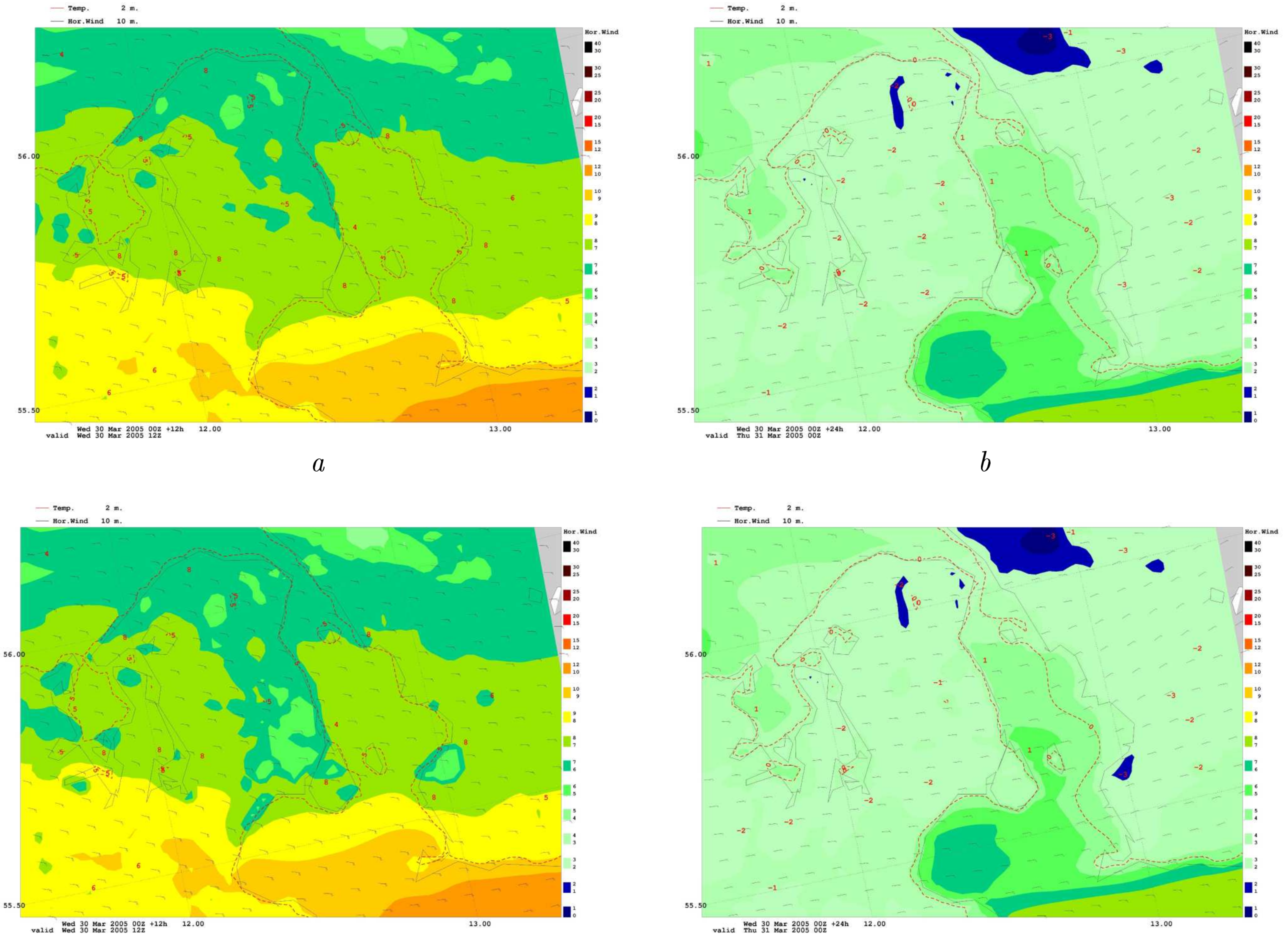
During 30 March of 2005, in the studied area the typical meteorological conditions were characterized by the easterly winds with velocities of 4–7 m/s. The relative humidity ranged from 69 to 98 %. During the day, the maximum temperature observed was 6.4 °C, and minimum value was — 0.9 °C at 24 UTC. The studied area is almost cloud free at the beginning, and then it diminished to zero. The center (60°N, 15°E) of the high pressure system was located over Sweden at 00 UTC on 30 March 2005, then it separated into two centers and shifted southward and westward during the day changing pressure from 1022 to 1031 hPa. The sounding diagrams of Jægersborg station in the low layers showed the presence of inversions at 00 and 12 UTC on 30 March 2005, and typical vertical temperature profile at 00 UTC on 31 March 2005. The wind patterns remained of the eastern wind directions with velocities of up to 10 m/s at the low layers up to 850 hPa level.

Roughness

As seen in fig. 2, the increased roughness in urbanized areas (suburbs of the Copenhagen and Malmö) changed the structure of the surface wind field. In particular, during day time the wind velocity over these urban areas is lower by 1–3 m/s (fig. 2, *c*). The increase of roughness up to 2 m decreases velocities by 1–4 m/s and areas, where this effect is visible, became larger and more pronounced not only near CPH and MAL, but also for other less urbanized cities. During the night this effect is smaller. As shown in tabl. 1, for roughness of 1 m, the difference of more than 2 m/s is observed.

A relatively flat maximum during 9–12 UTC is observed for CPH, and at 12 UTC — for MAL. For roughness of 1 m, the average differences in velocities are 1.8±0.4 and 1.4±0.5 m/s for CPH and MAL, respectively. For roughness of 2 m, the average changes in velocities are 2.4±0.6 and 2±0.6 m/s for the same urban areas, respectively. Moreover, for both roughness values this difference is on average 1.3 times larger for CPH compared with MAL.

For temperature, a change in roughness does not contribute significantly compared with wind (tabl. 1). On a daily cycle, for both roughness values, approximately on average these differences are 0.14±0.17 and 0.05±0.09 °C for CPH and MAL, respectively. Although mostly



a *b*

c *d*

Fig. 2. DMI-HIRLAM simulated wind at 10 m and temperature at 2 m fields for roughness of 0.05 m (*a, b*) vs. modified roughness of 1 m (*c, d*) for 12 (*a, c*) and 24 (*b, d*) hour forecasts on 30 March 2005.

Table 1. Diurnal variation on 30 March 2005 of difference fields for wind velocity at 10 m and temperature at 2 m for roughness values of 1 and 2 m for the Copenhagen (CPH) and Malmö (MAL) urbanized areas

Difference in fields	Wind velocity at 10 m, m/s				Temperature at 2 m, °C			
Roughness, z_0	1 m		2 m		1 m		2 m	
Urb Area UTC term	CPH	MAL	CPH	MAL	CPH	MAL	CPH	MAL
00	1.59	1.09	2.15	2.04	0.00	0.00	0.00	0.00
03	1.82	1.35	2.42	1.81	0.14	0.05	0.20	0.07
06	2.01	1.30	2.30	1.73	0.08	0.03	0.13	0.05
09	2.46	2.15	3.31	2.96	0.00	0.00	0.00	0.00
12	2.42	2.21	3.34	3.08	−0.05	−0.03	−0.07	−0.03
15	2.07	1.99	2.86	2.76	0.00	−0.02	0.00	−0.03
18	1.56	1.22	2.01	1.64	0.28	0.21	0.37	0.27
21	1.36	0.90	1.76	1.17	0.22	0.08	0.28	0.08
24	1.14	0.71	1.47	0.94	0.39	0.17	0.50	0.16

the difference is positive, during 12–15 UTC the increased roughness slightly increasing temperature over the urbanized areas

Albedo

The albedo for urban vs. non-urban areas can be higher or lower, depending on roof and wall materials, street surfaces/ground cover, level of vegetation, snow, etc. Therefore, we considered in our sensitivity study the following range of urban albedo variation (for 100 % of urban class): 0.48 to 0.8. It was found that changes in albedo have the highest influence on the temperature field over the urbanized areas between 9–15 UTC, reaching during this time the maxima of difference in 2 and 1.8 °C for CPH and MAL, respectively. But it is less than 0.5 °C during the late evening — early morning period. Similarly, for wind velocities, except, that the difference between wind velocity fields is often more than two times larger for CPH vs. MAL urbanized areas. The maxima of difference are 1.6 and 0.8 m/s for CPH and MAL, respectively, and both are observed at 15 UTC. But this difference is less than 0.2 m/s during the late evening — early morning period.

Anthropogenic Heat Flux

As seen in fig. 3, the incorporation (in the ISBA scheme) of anthropogenic heat flux (AHF) for urban cells of domain shows well pronounced differences for simulated wind fields at 10 m. Note, starting of 16 UTC term the difference became visible, at first, over the CPH urban area and it is approximately of 0.5 m/s. Then, the area faster extended more toward the inland of the Island of Zeeland and rapidly increases up to 1.5 m/s at 18 UTC. It is also became well pronounced over and to the west of MAL (up to 1.5 m/s). During the late evening — night — early morning hours the difference became the largest reaching a maximum of 2.1 m/s, and again by 10 UTC there is no difference visible between two runs. For of AHFs smaller magnitudes (i. e. for 100, 50, and 10 W/m^2) the highest difference (during the night time) reaches of 1.6, 0.8, and 0.2 m/s. Moreover, this difference is slightly higher (by 0.1–0.2 m/s) for MAL compared with CPH.

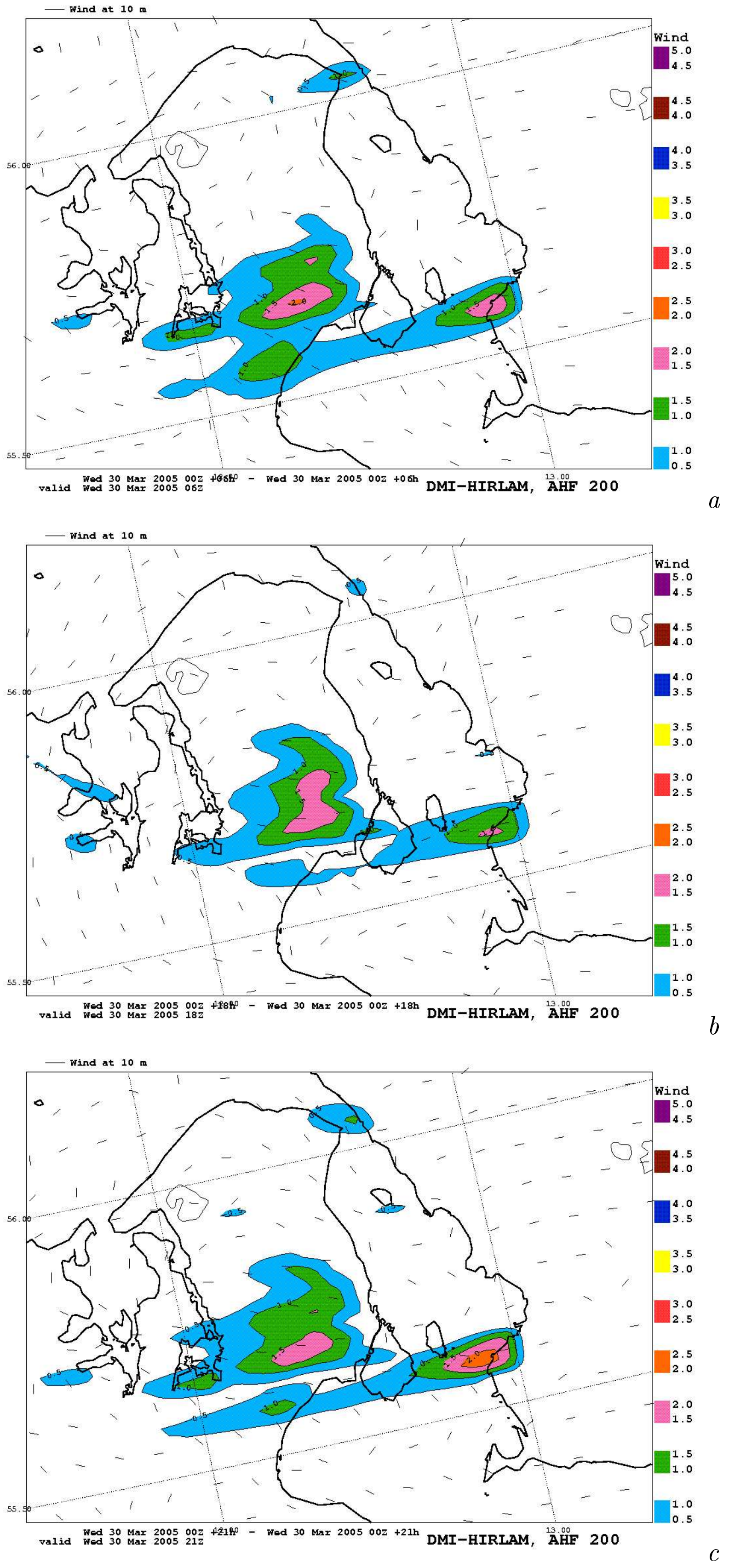


Fig. 3. Difference plots (between outputs of the DMI-HIRLAM control vs. modified run with addition of anthropogenic heat flux up to 200 W/m^2) for wind velocity at 10 m at: *a* — 06, *b* — 18, and *c* — 24 UTC forecasts on 30 March 2005.

For temperature (tabl. 2), for all terms the AHF addition increased the temperature above the urban cells, except that it is smaller during 9–15 UTC with a minimum at noon. On average, it is higher for CPH compared with MAL. For a given range of selected fluxes, the diurnal average increase in temperature at 2 m varied from 0.09±0.05 to 1.1±0.6 °C for the CPH urban area. For MAL, it is comparable with CPH — i. e. from 0.08±0.05 to 1±0.7 °C, although for higher values of AHF the variability became larger. The range of maximum possible

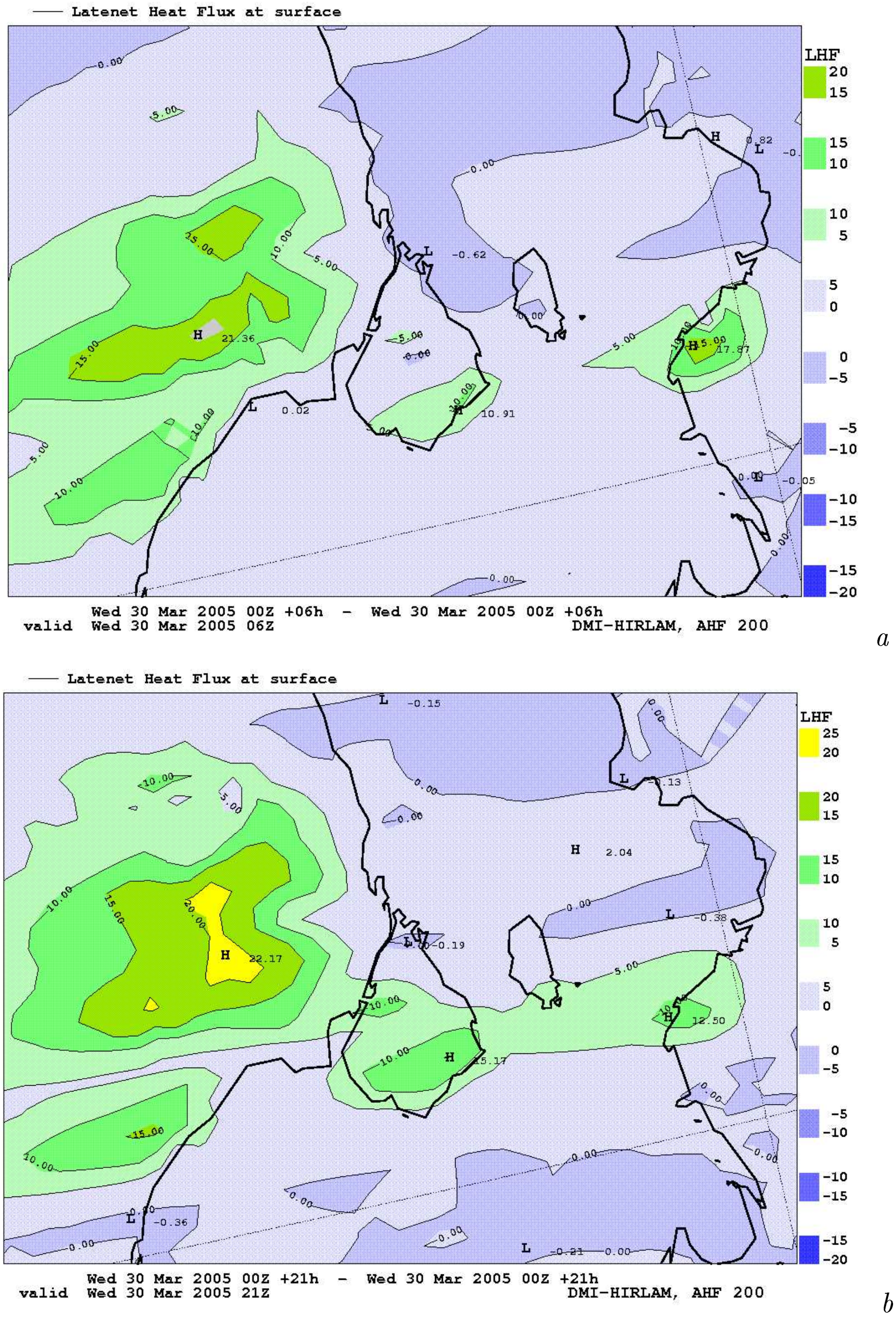


Fig. 4. Difference plots (between DMI-HIRLAM control run vs. added anthropogenic heat flux up to 200 W/m^2) for the latent heat flux at the surface for 06 (*a*) and 21 (*b*) UTC forecasts on 30 March 2005.

Table 2. Diurnal variation on 30 March 2005 of difference fields (in °C) for temperature at 2 m for the anthropogenic heat flux values for the Copenhagen (CPH) and Malmö (MAL) urbanized areas

Anthropogenic Heat Flux, W/m^2	200		100		50		10	
Urb Area UTC term	CPH	MAL	CPH	MAL	CPH	MAL	CPH	MAL
00	−0.80	−0.32	−0.54	−0.51	−0.33	−0.30	−0.08	−0.07
03	−1.36	−1.27	−0.87	−0.80	−0.50	−0.42	−0.11	−0.09
06	−1.36	−1.34	−0.90	−0.87	−0.53	−0.49	−0.11	−0.10
09	−0.70	−0.40	−0.38	−0.22	−0.20	−0.12	−0.04	−0.03
12	−0.38	−0.24	−0.20	−0.13	−0.10	−0.06	0.00	−0.01
15	−0.41	−0.28	−0.22	−0.15	−0.12	−0.08	−0.02	−0.02
18	−1.12	−0.78	−0.84	−0.54	−0.54	−0.37	−0.12	−0.09
21	−1.75	−1.66	−1.24	−1.20	−0.80	−0.71	−0.15	−0.15
24	−1.93	−2.27	−1.39	−1.59	−0.87	−0.77	−0.15	−0.13

temperature increase varied within 0.15–1.9 °C and 0.15–2.3 °C for CPH and MAL, respectively. Moreover, on average, this increase is 1.2–1.4 times larger for CPH compared with MAL.

As shown in fig. 4, the AHF contribution modifies the latent heat flux (LHF) over the grid cells of urbanized areas (it is well underlined by izolines around the CPH and MAL) and surroundings. The higher will be the magnitude of AHF added, the longer time will be visible the influence on a diurnal cycle. This effect is more pronounced during the night time. During the daytime its influence almost disappears, especially during 11. . . 16 UTC. On average, it is higher for CPH compared with MAL. For a given range of selected AHFs, the diurnal average decrease in LHF varied up to 25 and 18 W/m^2 for the CPH and MAL urban areas, respectively, with a large variance. Additionally, the analysis of sensible heat flux showed that over the urbanized areas it might be additionally changed throughout the day by up to 200 W/m^2 depending on the anthropogenic fluxes' values.

Conclusions

In this note we evaluated diurnal variability of meteorological variables for the ISBA land surface scheme as a function of parameters: roughness, albedo, and anthropogenic heat flux (AHF). The specific case study on 30 March of 2005 was analyzed employing the DMI-HIRLAM model with high resolution of 1.4 km, and considering impact of parameters on the urbanized areas of Copenhagen (CPH), Denmark and Malmö (MAL), Sweden.

It was found that changes in roughness modify the structure of the surface layer wind field over urban areas. During the day time the wind velocities are lower by 1–4 m/s. For scale-roughness of 2 m, this effect became more visible and pronounced not only near CPH and MAL, but also for other less urbanized areas; during the night this effect is smaller. For roughness of 1 (2) m, the average differences in velocities are 1.8 (2.4) and 1.4 (2) m/s for CPH and MAL, respectively. For temperature, roughness change does not contribute significantly compared with wind.

Changes in albedo have the highest influence on the temperature field for the period of maximal solar radiation to the surface (e. g., 9–15 UTC), reaching maxima of difference in 2 and 1.8 °C for CPH and MAL, respectively. But it is less than 0.5 °C during the late evening —

early morning period. Similarly, for wind velocities, except, that the difference between wind velocity fields is often more than two times larger for CPH vs. MAL urbanized areas.

Changes in anthropogenic heat flux showed (starting at 16 UTC) well pronounced differences for simulated wind fields over urban cells. Then, the area is extended more toward the inland of Zeeland, and difference is rapidly increased up to 1.5 m/s by 18 UTC. During the late evening — early morning period, the difference became larger, and by 10 UTC — there is no difference visible between control and modified runs. For AHF — 200, 100, 50, and 10 W/m^2 — the highest difference (during the night time) reaches of 2.1, 1.6, 0.8, and 0.2 m/s. For temperature, for all terms AHF increased the temperature above the urban cells, except that it is smaller during 9–15 UTC with a minimum at noon. For both urbanized areas, on average (max 2.3 °C), this increase is up to 1 °C with a large variance. The higher is a value of AHF, the longer time is visible its influence on a diurnal cycle for the latent heat flux; and this effect is more pronounced during the night time. During 11–16 UTC, the AHF influence is almost disappeared. For a given range of AHF, the diurnal average decrease in latent heat flux is up to 25 and 18 W/m^2 for the CPH and MAL, respectively. Analysis of sensible heat flux showed that over the urbanized areas this flux might be additionally changed by a value of up to the included anthropogenic heat flux.

Based on these results it can be seen that in specific meteorological situations the urban effects can be considerable not only for large megapolices, but also for relatively small cities. The modification of the effective roughness and urban heat fluxes approach gives a possibility to incorporate the main urban effects into high-resolution NWP models without a considerable increase of the computation time. Hence, it makes such modifications suitable for operational forecast purposes.

However, it does not give a possibility to describe the urban roughness sublayer, which is a critical region where people live and where pollutants are emitted. For this purpose a new analytical model of the mean wind and momentum flux profiles in such sublayer [19] can be used for diagnosis of surface layer characteristics (e. g. wind at 10 m) in NWP and for lowest levels wind and turbulent input fields for dispersion modelling. Another alternative is resolving of the urban surface layer in NWP models with higher vertical resolution and specific treatments of the urban sub-layer flow and energetics [3–5, 8].

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